



Slavsko Mountain Living Lab

Concept, Implementation, and Development Plan

1. Introduction



Mountain regions whose economies depend on winter tourism are particularly sensitive to climate variability and long-term climatic change. In such environments, even relatively small shifts in temperature and precipitation regimes can significantly alter snow-cover dynamics, thereby affecting the duration and reliability of ski

seasons, the functioning of tourism infrastructure, and the economic stability of local communities.

In the Ukrainian Carpathians, Slavsko represents one of the most important winter tourism centres. Over recent decades, the region has experienced not only gradual climatic changes but, more importantly, increasing intra-seasonal variability and instability of snow conditions. This growing unpredictability creates substantial challenges for tourism operators, local authorities, and businesses whose activities rely on consistent winter conditions.

In response, the **Slavsko Mountain Living Lab (SMLL)** has been established within the framework of the SUNRISE Erasmus+ Project. The Living Lab is designed to support the development of an operational, user-oriented climate service that integrates scientific analysis with stakeholder needs and provides a basis for informed decision-making under conditions of increasing climatic uncertainty.



2. Concept and Justification

The conceptual foundation of the Slavsko Mountain Living Lab lies in recognising a fundamental limitation of conventional climate analysis. While traditional approaches provide robust assessments of long-term trends and mean changes in climatic variables, they do not adequately address the needs of sectors such as winter tourism, where decisions depend on the timing, stability, and reliability of snow conditions within individual seasons.

For tourism operators, the central question is not simply how the climate is changing over decades, but rather when snow conditions will be sufficient, how long they will persist, and how



frequently they may be disrupted. These are inherently operational questions that cannot be answered through average values alone. Instead, they require a detailed understanding of intra-seasonal dynamics, variability, and thresholds that define functional conditions for tourism activities.

The empirical basis for this shift in perspective is provided by a long-term analysis of snow-cover dynamics at the Slavsko meteorological station, covering the period from 1948/49 to 2019/20. The results indicate a weak but persistent decline in the duration of snow cover and a gradual reduction in snow depth. However, these trends are accompanied by pronounced interannual and multi-decadal variability. At the same time, a statistically significant decrease in winter severity suggests that thermal conditions are changing more rapidly than snowfall itself. As a result, periods of stable snow cover are becoming shorter and more fragmented, while the occurrence of discontinuous snow conditions is increasing. More detailed information on the statistical analysis of winter-season meteorological data from the Slavsko station can be found in *Khomenko, I., and Marchyshyn, R. (2025), Trends and variability of snow cover in Slavske during 1948–2020 under climate change, Ukrainian Hydrometeorological Journal, No. 34–35, pp. 32–43.* <https://doi.org/10.32782/uhj.34-35.2025.03>.

These findings lead to a critical conclusion: the main challenge is not simply a reduction in snow availability, but a loss of stability and predictability. This has direct implications for the operation of winter tourism systems, where reliability is often more important than absolute quantities. Addressing such a complex and dynamic problem requires an approach that goes beyond static climate analysis.

The Living Lab concept has therefore been adopted as a methodological framework that enables the co-creation of climate services. Within this framework, scientific knowledge is developed in continuous interaction with stakeholders. Researchers provide structured climate diagnostics, while users define what constitutes meaningful and usable information. Through iterative feedback and refinement, the resulting tools and indicators are aligned with real-world decision contexts. In this way, the Living Lab serves as a bridge between science, policy, and practice.

3. Implemented Activities and Achievements

The development of the Slavsko Mountain Living Lab has already resulted in a substantial analytical and technical foundation. A comprehensive framework for climate diagnostics has been established based on daily observational data, allowing for a detailed examination of snow-cover characteristics. This includes not only the duration of snow cover but also its temporal structure, distinguishing between stable and unstable periods, as well as capturing the processes of accumulation and melt. In addition, synthetic indicators of snowiness and winter severity have been developed to provide an integrated view of seasonal conditions.

A particularly important achievement has been the transition from standard climatological variables to indicators that are directly relevant for decision-making. Rather than focusing on aggregate measures, the analysis emphasises aspects such as the duration of stable snow cover, the timing of seasonal transitions, and the frequency of interruptions within the snow season. These indicators are more closely aligned with the operational needs of tourism stakeholders and therefore form the basis for a user-oriented climate service.



To support the practical use of these data, an interactive application has been developed using Shiny (R). This tool allows users to visualise and explore climate and snow data in an intuitive and flexible manner. By enabling the comparison of different winters, the exploration of variability, and the interpretation of snow stability conditions, the application transforms static datasets into a dynamic decision-support environment. It also enhances transparency by allowing stakeholders to directly engage with the underlying data rather than relying solely on expert interpretation.



Figure 3.1 – Conceptual Design of an Application for an Interactive Climate Service in a Mountain Ski Living Lab (Blueprint)

The Living Lab has been conceptualised as a multi-stakeholder platform that brings together representatives of the tourism sector, local authorities, community organisations, and academic institutions. Although stakeholder engagement is still at an early stage, the structural framework for co-creation has been established, providing a solid basis for future collaboration and iterative development.

In parallel, the Living Lab has been integrated into the educational activities of the project. It serves as a real-world training environment for doctoral students, who gain experience in climate data analysis, climate service development, and stakeholder interaction. This integration ensures that the Living Lab contributes not only to local adaptation efforts but also to the development of human capacity in the field of climate services.

An additional component of the Living Lab is an air quality monitoring station installed at the Slavsko meteorological station (fig. 3.2). Based on an Arduino platform, the station measures atmospheric pressure, air temperature, relative humidity, particulate matter (PM1.0, PM2.5, PM10), and carbon dioxide (CO₂). Data from the station are transmitted in real time to [the ThingsBoard](#)



platform, where they are publicly accessible. This component extends the observational capabilities of the Living Lab and introduces a real-time dimension that complements long-term climate analysis. It also supports transparency, public engagement, and future integration of environmental monitoring into climate services.

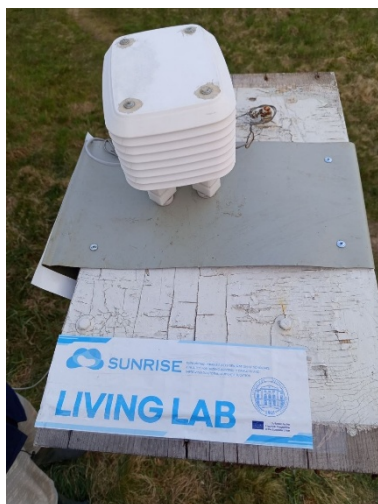


Figure 3.2 – Photographs of the Arduino-based air quality monitoring station installed at the Slavsko meteorological station



Video 3.1. – From Lab to Field: Installing an Arduino-Based Air Quality Monitoring Station in Slavsko



4. Identified Gaps and Development Needs

Despite the progress achieved, the current stage of the Living Lab remains transitional. While the analytical and technical foundations are well developed, several key elements required for a fully operational climate service are not yet in place. In particular, the integration of real-time climate and snow data remains limited, and the system does not yet provide explicit decision-support outputs such as operational thresholds or probabilistic assessments.

Furthermore, stakeholder engagement, although conceptually embedded, requires more structured implementation through formalised co-creation processes. The absence of forecasting capabilities and scenario-based tools also limits the ability of the Living Lab to support forward-looking decision-making. Finally, the connection between climate indicators and economic considerations remains underdeveloped, which restricts the practical applicability of the system in planning and investment decisions.

5. Planned Future Development

The further development of the Living Lab will focus on transforming the existing analytical framework into a fully operational climate service. This includes the integration of real-time data from an expanded monitoring network, enabling the system to support not only retrospective analysis but also ongoing decision-making.

At the same time, efforts will be directed towards the development of decision-support tools based on clearly defined operational thresholds and probabilistic indicators. This will allow users to move from descriptive information to risk-based decision-making.

Stakeholder engagement will be strengthened through structured consultations and iterative testing of tools in real-world conditions, ensuring that the system evolves in line with user needs. In parallel, the integration of seasonal forecasts and climate projections will extend the temporal scope of the Living Lab, enabling both short-term and long-term planning.

A further priority is the integration of climate information with economic considerations, including the assessment of risks, costs, and adaptation strategies. This will support the development of comprehensive approaches to managing tourism systems under conditions of climatic uncertainty.

6. Expected Impact

The continued development of the Slavsko Mountain Living Lab is expected to enhance the resilience of winter tourism systems by improving the quality, accessibility, and usability of climate information. It will strengthen the connection between scientific research and practical decision-making, support evidence-based planning, and contribute to the development of professional competencies among early-career researchers.

At a broader level, the Living Lab will serve as a prototype for climate services in mountain regions, demonstrating how scientific analysis, stakeholder engagement, and digital tools can be integrated into a coherent and effective system. Its methodology and tools are expected to be transferable to other regions facing similar challenges.



7. Conclusion

The Slavsko Mountain Living Lab represents a significant step towards the development of operational climate services tailored to the needs of mountain tourism. By combining long-term climate diagnostics, interactive tools, stakeholder engagement, and real-time environmental monitoring, it establishes a comprehensive framework for addressing climate-related challenges in tourism-dependent regions.

While further development is required to achieve full operational capacity, the existing foundation demonstrates strong potential. With targeted advancements, the Living Lab can evolve into a robust and scalable model for supporting climate adaptation under conditions of increasing climatic uncertainty.

The concept of the Living Lab will be presented at the EGU General Assembly 2026 within Session CL3.2.6 “Climate Services – From Science to Action” (Wednesday, 6 May, 14:00–15:40). The corresponding abstract is available online: *Khomenko, I., Ovcharuk, V., and Marchyshyn, R. (2026), Establishing a Mountain Living Lab for Climate Services in Slavsko (Ukrainian Carpathians), EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-9986, <https://doi.org/10.5194/egusphere-egu26-9986>*